Teachers' Implementation of Project-Based Learning: Lessons from the Research Goes to School Program

Nicole D. Cook
York County School Division, Virginia, USA

Gabriela C. Weaver
University of Massachusetts, Amherst, USA

Abstract

Research Goes to School (RGS) is a professional development program that focuses on high school teachers of science, technology, engineering, and mathematics (STEM) subjects. This collective case study examines RGS participants and their use of project-based learning (PBL) as they implemented curricular units that they developed at the RGS summer workshop. Based on the analysis of the data from the observations, the RGS participants exhibited partial fidelity of implementation to the features of PBL. Analysis of the data from the interviews indicated that participants were aware of features of PBL that they were not able to fully implement. Participants also identified several supports, particularly from the RGS program such as being able to order materials to implement their units, as well as supports that were specific to their teaching contexts. The findings suggested that the professional development program had some positive if limited influence on teachers' instructional practices. This study highlights the need for professional development to enhance teachers' content knowledge as well as their knowledge of pedagogy and to promote collaboration between teachers and professional development providers, particularly once teachers are in their classroom contexts.

Correspondence concerning this article should be addressed to: Gabriela C. Weaver,
Center for Teaching & Faculty Development, University of Massachusetts Amherst, 140 Hicks Way, 301 Goodell Building, Amherst, MA 01003 (gweaver@umass.edu)

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Introduction

There is worldwide recognition that scientific and technological capabilities are needed to address global issues (e.g., climate change, resource availability) that require all citizens, not just those who will pursue science degrees and careers, to have a solid science education that addresses the nature of science as well as basic science concepts ("Joint G8+ Science Academies' Statement on Education for a Science-Based Global Development," 2011). In the US, the goal of providing all students with a solid science education is part of a larger program to encourage more students, particularly those from underrepresented groups, to pursue STEM degrees and transition into the STEM workforce (NRC, 2011). However, there is evidence that there are serious barriers to achieving these goals.

Although increasing proportions of US high school graduates had taken advanced science and math courses such as calculus and physics between 1990 and 2009, less than a third of 2009 high school graduates had completed a three course sequence that included biology, chemistry, and physics (Aud, et al., 2012). Additionally, students' performance on the National Assessment of Educational Progress (NAEP) revealed serious performance issues and achievement gaps including substantial proportions of students performing below the basic level on the 2009 science assessment (National Center for Education Statistics [NCES], 2011) as well as performance gaps by race, gender, income and ethnicity on the 2009 (NCES, 2011) and 2011 (NCES, 2012) science assessments. The 2011 science assessment also revealed positive relationships between the frequency with which students were engaged in hands-on and collaborative activities and performance on the assessment. This finding suggests that reform-oriented math and science instruction can improve student learning and address the deficiencies revealed in the NAEP.

Skills and Standards for the 21st century

In 2012, the National Research Council (NRC) released *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas,* a new framework for science education standards. The *Framework* draws upon existing standards documents as well as reports on different aspects of the US educational system. The *Framework* is grounded in a view of science instruction as a means to gradually build students' understanding of a limited number of essential concepts through engaging students in activities that draw upon their prior knowledge and experiences and reflect the practices of scientists and engineers. The ultimate goal is to provide all students with a high quality education that will serve as the foundation of a lifetime of learning. While the authors did not identify specific instructional strategies or curricula to accomplish this goal, they did describe the implications of the *Framework* and the subsequent *Next Generation Science Standards (NGSS)* (NGSS Lead States, 2013) for curriculum and instruction as well as other aspects of the US education system.

A key element of the *Framework* is the inclusion of the dimension called "scientific and engineering practices" (NRC, 2012, p. 29). This dimension is perceived as critical to building students' understanding of the nature of science and engineering, promoting meaningful learning of science content, and students' motivation and interest in science and engineering. Furthermore by defining and focusing on practices the authors argue that students will gain a broader view of the science and engineering enterprises that goes beyond experimental design and highlights the role of evidence-based argumentation in the development of scientific knowledge and engineering solutions. The framework identifies eight scientific and engineering practices as well as potential learning progressions and end of school outcomes for each practice.

In addition to the framework and *Next Generation Science Standards*, the Partnership for 21st Century Skills proposed its own framework to prepare students to live and work in the twenty-first century (Partnership for 21st Century Skills, March 2011). Besides emphasizing core and interdisciplinary content, the *Framework for 21st Century Learning* identifies skills in the following domains (Partnership for 21st Century Skills, December 2009, March 2011):

1. Life and career (e.g., leadership, flexibility)
2. Learning and innovation (e.g., communication, collaboration)
3. Information, media, and technology (e.g., information and media literacy)

Project-based learning (PBL) is an instructional strategy that is well-suited to address both of these frameworks.

Project-based learning (PBL)

The model of PBL used in this study comes from the Buck Institute for Education (BIE) (2003), which defines it as "a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed products and tasks" (p. 4). Project-based learning is similar to, but not synonymous with, problem-based learning. There appear to be disagreements about which strategy is more structured in terms of determining the ultimate outcome or solution within a unit (BIE, 2003; Combs, 2008; Savery, 2006). One distinguishing feature of project-based learning is that there is greater expectation that students will produce concrete intermediate and final products as a result of the experience (BIE, 2003, Krajcik, Blumenfeld, Marx, & Soloway, 1994; Savery, 2006). However, after comparing the model used in this study with other published descriptions of problem- and project-based instructional strategies (Gallagher, Stepien, Sher, & Workman, 1995; Krajcik et al., 1994; Savery, 2006), the authors concluded that there was sufficient overlap between the two in terms of their use of instructional strategies (i.e., engagement of students in collaborative, extended investigation of open-ended, ill-structured problems/ questions) that justified examining literature on both methods in order to develop a working model of PBL for this study. Publications on both project- and problem-based instructional strategies were examined, and the following features were explicitly or implicitly identified as being critical to both methods of instruction and will be highlighted in our cases:

1. Student-driven and student-centered instruction: PBL is student-centered and student-driven (BIE, 2003; BIE, 2009b; Gallagher, et al., 1995; Krajcik, et al., 1994; Savery, 2006). Students are responsible for making important decisions about how address the challenges presented in the PBL unit.
2. Content in context: PBL uses authentic, real-life topics to provide context for content learning, which makes learning disciplinary concepts relevant and engaging for students (BIE, 2003; BIE, 2009b; Gallagher, et al., 1995; Krajcik, et al., 1994; Savery, 2006). Furthermore, PBL is intended for students to learn, rather than apply, content.
3. Use of the driving question: PBL uses an ill-structured, open-ended driving question or problem that allows students to create their own solutions or final products in response to it (BIE, 2003; BIE, 2009b; Gallagher, et al., 1995; Krajcik, et al., 1994; Savery, 2006).
4. Student collaboration: PBL requires students to collaborate and interact with their peers in order to successfully complete the unit. (BIE, 2003; BIE, 2009b; Krajcik, et al., 1994; Savery, 2006).
5. Substance and rigor: PBL engages students in extended investigations where they can pose questions, gather information, and evaluate their findings as they develop solutions to the problem or driving question (BIE, 2003; BIE, 2009b; Gallagher, et al., 1995; Krajcik, et al., 1994; Savery, 2006).

6. Multiple products and opportunities for feedback: Through PBL students generate multiple products and have multiple opportunities to receive feedback as they work (BIE, 2003; BIE, 2009b; Gallagher, et al., 1995; Krajcik, et al., 1994; Savery, 2006).
7. Other characteristics: PBL allows students to develop their skills in areas such as technology, critical thinking, self-assessment, and problem-solving (BIE, 2003; BIE, 2009b; Gallagher, et al., 1995; Krajcik, et al., 1994; Savery, 2006). Additionally, PBL can provide opportunities for students to interact with outside experts and community members (Gallagher, et al., 1995; Krajcik, et al., 1994).
8. Teacher as facilitator: In PBL, the teacher acts as a facilitator who enables students to find their own solution to the driving question or problem (BIE, 2003; Gallagher, et al., 1995; Krajcik, et al., 1994; Savery, 2006).
9. Assessment: PBL incorporates assessment that is performance-based and encompasses both skills and content (BIE, 2003; Gallagher, et al., 1995; Savery, 2006).
10. Final products: In PBL, students give a public presentation of their final products or solutions (BIE, 2009b; Gallagher, et al., 1995; Krajcik, et al., 1994).

PBL is well-suited to engage students in the science and engineering practices from the *Framework* such as "defining problems… planning and carrying out investigations…analyzing and interpreting data…constructing explanations and designing solutions…[and]obtaining, evaluating, and communicating information" (NRC, 2012, p. 42). Likewise, by engaging students in collaborative student-centered activities that allow students to develop various skills as they work on real-world problems, PBL is also aligned with the skills identified in the 21st century framework. Furthermore, hands-on and collaborative science instruction were identified as having positive relationships to student learning (NCES, 2012), which suggests that PBL is a strategy that could address current deficiencies in science education.

Background

Teachers' Implementation of PBL

Studies of teachers at the K-12 level who have implemented PBL indicate there are similarities to the experiences of teachers who implement inquiry-based instruction. Multiple researchers have noted that teachers struggle with issues of content coverage (Combs, 2008; Ladewski, Krajcik, & Harvey, 1994; Lee & Bae, 2008; Marx, et al., 1994; Rogers, Cross, Gresalfi, Trauth-Nare, & Buck, 2011; Rosenfeld, Scherz, Breiner, & Carmeli, n.d.) and control (Combs, 2008; Ladewski, et al., 1994; Lee & Bae, 2008; Marx, et al., 1994) as they implement PBL. Teachers often doubt that students will learn all of the content that they feel needs to be covered through a PBL unit, thus they often want to impose more structure so that students do more common rather than individualized tasks (Combs, 2008; Ladewski, et al., 1994; Marx, et al., 1994) or they revert to more traditional styles of instruction (Lee & Bae, 2008; Rogers, et al., 2011).

Other researchers have noted the role of teachers' beliefs. In a case study of three teachers, Rogers and colleagues (2011) found that teachers who held student-centered or inquiry-centered orientations were more likely to implement PBL as intended than the teacher who was content-focused. In a case study of four middle school teachers, Marx and colleagues (1994) noted that teachers' beliefs about students' inability to work independently led the students to have trouble working independently. The teacher in Goodnough and Cashion's (2006) study had to confront her beliefs about group work and its assessment. Ladewski, Krajcik, and Harvey (1994) noted that when the teacher-collaborator profiled in their case study, Harvey, implemented her first PBL unit she encountered challenges as she tried to engage students in investigative and collaborative tasks because she was more oriented towards maintaining classroom order and covering content. They further noted that even though the teacher began to modify her beliefs and practices, she still experienced conflicts related to her prior beliefs regarding content coverage and control.

Teachers also struggle with facilitation of PBL. Combs (2008) and Goodnough and Cashion (2006) reported that teachers struggle not to lead students to answers through directed questioning or simply give students information. The teachers in Lee and Bae's (2008) case study managed this issue by asking a variety of questions, but still sometimes used a more traditional style of questioning to teach specific content. Marx and colleagues (1994) noted that teachers struggled to foster student collaboration and the management of the multiple tasks that are required in a PBL setting. Regarding the issue of collaboration, the experienced teacher in Lee and Bae's (2008) study worked on developing students' collaboration skills prior to implementing his PBL unit.

In a study of twenty-seven junior high school teachers from four high schools in Israel, Rosenfeld and colleagues (n.d.) found that teachers in their study focused on teaching PBL skills at the expense of content. They speculated that this imbalance occurred because addressing all of the aspects of PBL posed too great a "cognitive load" (Rosenfeld, et al., n.d., para. 10) given the limited time for professional development and instruction. Among their recommendations was for teachers' to integrate development of PBL skills into their regular classroom instruction. Contrary to the intention of PBL, the researchers also suggested teaching content before implementing PBL.

In his discussion of barriers teachers' encountered in their efforts to use reform-oriented strategies, Anderson (1995) noted the role of other educational stakeholders such as parents, colleagues, and students. These issues have been noted in the research on PBL. Researchers have reported that students can initially be resistant and need a period to adjust to the requirements of PBL (Combs, 2008; Goodnough & Cashion, 2006; Rogers, et al., 2011). Marx and colleagues (1994) described how one teacher in their case study struggled because he felt compelled to cover content due to the expectations of parents and his colleagues. However, Combs (2008) noted that the teacher in her study was helped by support from her administration.

The Research Goes to School Program

Research Goes to School (RGS) is an NSF-funded program that seeks to help high school teachers of STEM[1] subjects, particularly teachers in rural districts, to enhance their pedagogical and content knowledge and make their instruction more relevant to students. RGS offers a two-week intensive summer workshop, where teachers learn about PBL and current research on

[1] We are using the acronym "STEM" to reflect the fact that the audience for the workshop encompasses teachers from across these disciplines, and that they will focus their PBL units on their specific content area. Teachers were not expected to create units that included content from an area of science, technology, engineering, or math that was outside of the area(s) that they teach.

global challenge issues (e.g., renewable energy). Over the course of the workshop teachers collaborate in small groups to develop PBL units that address the state standards for their particular subject-areas (e.g., biology, mathematics) and use the research science from the workshop as a real-world context for the targeted STEM content to be addressed in the unit. RGS began offering professional development in June 2011 and used biomass to biofuels science as its initial context. This study focuses on the impacts of the second workshop that was offered in June 2012 after it was redesigned based on an evaluation of the pilot program.

The June 2012 workshop was structured as a PBL unit for teachers in which they developed curricular units to address the following driving question: What does it take to be an effective PBL teacher? To accommodate the content focus of the workshop an additional question for teachers to consider was: What do you need to know in order to incorporate biomass to biofuels research? Teachers were placed in discipline-based groups (biology, physical science, math, and technology) of three to four to respond to these questions by developing common PBL units for use in their classrooms during the subsequent academic year.

The professional development team consisted of three lead facilitators two of whom had prior experience teaching a course on PBL as well as a third member who was an expert on biofuels research. In addition there were three mentor teachers, two of whom had participated in the pilot year of RGS. The mentor teachers assisted participants as they made their units by offering advice and sharing their own experiences with PBL. Additionally, discipline-based education and science faculty were brought for one afternoon session to consult with participants as they began to develop the driving questions for their own curricular units.

In keeping with PBL's use of multiple products and opportunities for feedback participants completed a series of tasks related to developing their understanding of PBL. Each group had to research elements of PBL (e.g., assessment of student learning in PBL) and give a presentation to their peers. The actual creation of the PBL units was broken into smaller tasks (e.g., development of a driving question, writing standards-based learning objectives) to be completed over time. Each team was assigned a point of contact from the lead facilitation team who would review each component of the unit and offer feedback as the unit was created. For the development of their PBL units, teams assembled their units on web-based platforms of their choosing. Participants also had the opportunity to review and critique each others' PBL units prior to final day of the workshop. On the final day of the workshop, each team presented its completed instructional unit to the rest of the workshop participants.

The biofuels science content of the workshop was presented through a combination of research presentations and activities. During the first week of the workshop research scientists from a variety of disciplines (chemistry, engineering, botany), gave presentations on their particular area of expertise and its role in the larger biomass to biofuels research project. During the second week of the workshop teachers were engaged in biofuels-focused activities in order to enhance participants' understanding of concepts, such as the carbon cycle, and to model activities that they could include in their own units.

In accordance with PBL's focus on developing learners' metacognitive skills, the workshop was also characterized by regular use of written reflections that teachers completed at the end of each day. These reflections were debriefed at the start of each subsequent day by one of the lead facilitators. They often served as a starting point for discussion of issues such as how to define the elements of PBL or to address teachers' concerns as they arose during the workshop.

After teachers attended the workshop, additional support was provided through web-based resources. These included webinars, virtual field trips where teachers and their students could interact with scientists, and an online group where participants could exchange and access materials called STEMEd Hub. In terms of materials supports, teachers were given reference books on reformed instruction (Prensky, 2010) and strategies to incorporate energy concepts into secondary science and math courses (Metz, 2012) at the workshop. Additionally teachers received a stipend to purchase materials that they needed in order to implement their units during the academic year following the workshop.

Methods

Research Questions

Previous studies of teachers' use of PBL have contributed to our understanding of how teachers implement reform-based instructional strategies because they have shown some of the pitfalls, barriers, and supports that can occur as teachers attempt to implement reform-oriented instructional strategies. This study seeks to contribute to our body of knowledge about PBL implementation by investigating the following research questions:

1. How do teachers who have participated in the RGS professional development teach using PBL as they implement their instructional modules?
   i. To what extent are they able to implement the features of PBL in ways that align with PBL best practices?
   ii. In what ways do they deviate from best practices?
2. What are the perceived barriers and facilitators that influence teachers' implementation of their PBL modules?
   i. What do teachers report help and hinder their ability to implement their PBL modules?
   ii. What aspects of the RGS professional development do teachers report influence their implementation of their PBL modules?

Theoretical and Methodological Frameworks

The theoretical framework in this study is fidelity of implementation (FOI) as it has been conceptualized by Century, Rudnick, and Freeman (2010). In this framework FOI is defined as "the extent to which the critical components of an intended program are present when that program is enacted" (p. 202) where critical components are considered the defining features of the program to be implemented, in this case PBL.

The framework distinguishes between two types of critical components: structural and instructional. This study will focus on the instructional components of the framework. Instructional critical components are the aspects of the program that can be observed as teachers implement the unit because they focus on "participants' (in our case, teachers and students) behaviors and interactions as they enact the intervention" (Century, et al., 2010, p. 205). These are further subdivided into pedagogical components, which focus on the teacher's actions and student engagement components, which focus on the students' actions and responses to the curriculum.

The methodological framework for this research is case study as it is defined by Creswell (2007): "a qualitative approach in which the investigator explores a bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving, *multiple sources of information*…, and reports a *case description* and case-based themes" (2007, p. 73). Since this study examines teachers in their classroom contexts, during the academic year as they implemented their PBL units, this is what Creswell (2007) calls a "collective case study" (p. 75), where each case (i.e., teacher) was analyzed and then compared through a "cross-case analysis" (p.75).

Participants and Settings

Recruitment of participants for this study focused on in-service teachers who attended the summer RGS workshop[2]. These teachers had applied to participate in the RGS program. Prior to initiating the study, the principal at each participant's school was contacted via email and sent a letter describing the study along with a request for permission to conduct the study. After principal permission was obtained, each participant was contacted via email with a request to participate in the study. Seven participants were recruited from the eight in-service teachers who attended the 2012 workshop. The majority of participants worked in public high schools and taught introductory biology. All participants were assigned pseudonyms. Although, the students are not the focus of this study, parent consent and student assent (for minor students) and student consent (for students 18 and older) was sought regarding the use of data from the videotaped classroom observations. Information about the teacher participants from cohort 2 is summarized in Table 1. The table is organized to reflect the discipline-based teams from the RGS workshop.

Table 1. Cohort 2 Participants and Settings

Participant Pseudonym	Subject	PBL Unit Topic	Length of Unit (# of class periods observed)
N. Robards[1]	Biology	Ecology	7
E. Davies	Biology		13
B. Lewis	Biology		19
F. Johnson	Biology	Enzymes	11
T. Morris	Biology		10
R. Jefferson[2]	Biology	Calorimetry	6
S. Thompson[3]	PBL Elective	Alternative fuels	17

[1]This teacher worked at a private, religious school. [2]This teacher was also in the group that made the Enzymes PBL unit, but chose to implement a unit on a different topic; [3] This teacher did not implement the unit developed at the RGS workshop, The teacher self-taped implementation of the unit, some video data lost

Data Sources

During the academic year following the 2012 workshop, the first author observed as teachers implemented their PBL units. These observations were scheduled based on the teacher's schedule. Observations were recorded in digital format with a video camera along with written field notes. After teachers completed the PBL units, the researcher conducted a semi-structured

[2] The workshop participants include both pre-service and in-service teachers. This study focuses only on the experiences of the in-service teachers.

interview (Appendix A), which included questions about teachers' experiences implementing the unit, their perceptions of strategies for supporting and improving their implementation of the units, the influence of the RGS program, and lessons learned from the unit. These interviews were audio taped and notes were taken on a blank copy of the protocol.

Data Analysis

The field notes were transcribed and reviewed with the video data according to a rubric that was developed for this project. The development of the rubric was guided by literature on PBL, pre-existing rubrics, and video examples of PBL instruction (Buck Institute for Education, 2009a, 2009b, 2009c, 2010; Combs, 2008; Fouts, Brown, & Thieman, 2002; Galileo Educational Network, 2002-2005; Hmelo-Silver & Barrows, 2006, 2008; Johnson, Johnson, & Smith, 1998; Kolodner, et al., 2003; Piburn, et al., 2000; Supovitz & Turner, 2000; Yezierski & Herrington, 2011). In addition, a draft of the rubric was sent to two of the workshop facilitators, as both of them had relevant expertise in PBL. Their comments were used to modify the rubric indicator descriptions (S. Freemeyer, personal communication, August 4, 2011) (P. Ertmer, personal communication, August 16, 2011). After it was used to examine observations from the pilot year of the study, the rubric was further refined by examining additional literature (Barrell, 2010; Buck Institute for Education, 2003; Ertmer & Simons, 2006; Norton & Wiburg, 2003; Prensky, 2010; J. Savery, 2009; J. R. Savery, 2006; J. R. Savery & Duffy, 1995), additional conversation with the main PBL facilitator (P. Ertmer, personal communication, December 15, 2011), and through inter-rater reliability sessions. These efforts resulted in a final rubric that that addressed three domains of instruction: the role of the students, the role of the teacher, and the use of resources (Appendix B). Each indicator on the rubric was rated on a 1 to 3 scale where a rating of 1 represented the least desirable practice and rating of 3 represented the most desirable practice. For each teacher, all of the videos from the module lessons were reviewed along with the transcribed field notes and an overall rating for each rubric indicator was determined.

To assess the reliability of the rubric, inter-rater reliability analyses were conducted with two different colleagues in order to refine the definitions of the rubric indicators, establish rules for their use, and assess the reliability of the rubric. With the first colleague, the two raters rated and discussed videos for three teachers, and this served to further refine the rubric. With the second colleague, the two raters rated and discussed videos for two teachers. After two rounds they reached a final agreement level of 86%.

After rating teachers' videos using the rubric, it was evident that simply reporting average scores from the rubric would not adequately address the research questions about teachers' implementation of PBL, because they gave little detail on what teachers actually did. Thus, a case study approach was used to more fully represent teachers' efforts at implementation. In spite of its limitations as a quantitative analysis tool, the rubric was useful for construction of the case studies. The writing of case narratives and the cross-case analysis process were guided by Miles and Huberman (1994), Stake (2006), Yin (1981), and Creswell (2007). Construction of case narratives and the cross-case analysis was an iterative process of examining the data from individual cases and across all of the cases. This was initiated by using the rubric to write a series of questions to answer in the case narratives and using these questions to write narratives for each teacher (Yin, 1981). These initial descriptions were refined by writing a new series of questions that was grounded in the ten critical features of PBL identified for this study, which served as themes for the cross-case analysis (Creswell, 2007). These questions were then used to cluster indicators in the rubric and construct case analysis sheets for each teacher (Stake, 2006). The information in these sheets was then placed into a cross-case display table in order to search for patterns in the data (Miles & Huberman, 1994).

Detailed descriptions of how each feature of PBL was implemented across cases were written. This process involved noting patterns and then re-examining individual cases to verify the applicability of patterns to each teacher. Once the cross-case analysis was written, individual case narratives were written for three of the teachers to illustrate the breadth of how the features were implemented. The selection of illustrative cases was informed by Stake's (2006) suggestions on selecting cases, with regards to not simply choosing typical cases. Again, this involved careful examination of each participant's set of data to ensure a credible representation of each teacher's implementation.

Analysis of the data from interviews was guided by Hatch (2002) and Sandelowski (2000). The interviews were transcribed verbatim. Using NVivo 9 software, data from the interviews were sorted in typologies (Hatch, 2002) based on the categories of interview questions (e.g., implementation experience, lessons learned from implementation), and then further sorted into sub-typologies based on more specific aspects of the interview questions (e.g., challenges of implementation). Comments regarding the following topics were selected for further analysis: perceived challenges of implementation, perceived supports for implementation, perceived influences of the RGS online components, perceived needs from the RGS program, plans for changes to the PBL units, and perceived influence of the RGS summer workshop. Summaries of each participant's comments on these topics were written and examined against the research questions about teachers' perceptions of influences on their implementation (What do teachers report help and hinder their ability to implement their PBL modules? What aspects of the RGS professional development do teachers report influence their implementation of their PBL modules?) by identifying any common topic in the summaries (comments from 2 or more participants) and counting the number of participants who commented on an a given topic. Summary statements of these findings were written along with example comments and given to the participants for member checks.

Results

The three cases described below were chosen to illustrate the breadth of approaches teachers took to implement their PBL units. N. Robards' case illustrates a best case scenario with regards to teacher implementation and the resulting student products. B Lewis' case was more perplexing example with regards to the teacher's use of student-centered instruction and activities, but relative lack of rigorous content in the unit. Finally, F. Johnson's case served as a more in-between case.

Case 1: N. Robards'

Overview of case and unit. N. Robards was a biology teacher and department chair at a private, religious school. She did not have prior experience with PBL and described it as "different" for both herself and her students. She implemented her PBL unit on ecology in an introductory biology class. The unit's driving question was "How can we use organic waste products to produce an efficient biofuel for our school?" The unit was observed over the course of 7 class periods. During this time, students worked in small groups to complete a guiding packet on ecology concepts (e.g., carbon cycle, food webs) and other unit activities (e.g., written reflections), conducted and presented on one of three activities (composting lab, calorimetry lab, photosynthesis packet) and researched and prepared a final presentation to share their proposed solutions to the driving question with their peers.

Implementation of PBL features.

Student-centered and student-driven instruction. Leading up to the final project, students' level of choice was somewhat constrained. Initially students worked within their groups on teacher-set tasks, such as pages from the guiding packet and could make minor decisions such as which websites they would use to answer the questions in the packet. They could also choose from teacher-set options such as when they chose one of three activities (composting lab, calorimetry lab, photosynthesis packet) to complete and present to the class. When it came to the final product students had the most choice; they could design their own solutions and the format for their final projects.

Students were observed to work productively and stay on task with little prompting from the teacher. They were also observed dividing tasks between group members on their own and taking responsibility for working on the final product outside of class. The teacher supported students by suggesting timelines and intermediate tasks for students to complete along with the pages in the guiding packet, and handouts to guide activities like labs. Although such handouts to guide students on completion of activities were present, there was still some lack of clarity for students. This was evident for the final product, which had no rubrics or similar written guidelines to help students understand how their work would be evaluated on that aspect of the product. Students were observed to be confused regarding expectations for this aspect of the unit.

Content in context. Initially the focus of the unit was on the ecology concepts of the unit. Students would work on activities such as answering questions about food webs, energy pyramids, and the carbon cycle and each group would share its responses during a class discussion. During these discussions the teacher would raise ties to the outside world or the project. For example, in the fourth observation of the unit, the teacher had students construct the carbon cycle using vocabulary words she provided. During the discussion of the carbon cycle, the teacher brought up ties between the carbon cycle and global warming and encouraged students to think about how the carbon cycle tied to the unit project. In this same lesson during a discussion of energy differences in organic compounds, the teacher talked about how the project could relate to students' future lives in terms of their energy choices. As the unit progressed the real-world context of the project became more prominent as students focused on creating their solutions to the driving question, which focused on the school. As students worked they were observed to consider issues such as the school's energy expenditures and where place their proposed solutions to the unit's driving question, such as compost piles (a lab activity in the unit), on the school's property. On the final day of the unit, after all of the students presented their solutions, the teacher wrapped up the unit by describing how students' projects might be used to make proposals for the school and how the products could be used in another teacher's environmental science class.

Use of the driving question. The driving question ("How can we use organic waste products to produce and efficient biofuel for our school?) was posted on the board throughout the unit. Additionally, the teacher used strategies such as revisiting the questions and highlighting key words in the question or asking students to give the meaning of words in the question. Finally, the teacher emphasized the question during class discussions and focused students' attention on making ties between the driving question and the unit activities. For example, when students presented their lab results to the class, the teacher reminded students to tie their labs to the driving question and revisited this tie after all of the students presented their lab findings by asking why the students should be interested in biofuels and noting the importance of the word "How" versus "What" in the driving question.

Student collaboration. Students worked in small groups throughout the unit and generally appeared to work productively in terms of conferring with one another and contributing to group tasks. The teacher's primary strategy to facilitate collaboration was to encourage students to help one another or suggest ways for group members to contribute. The teacher also included a group processing document for students to complete at the end of the unit.

Substance and rigor. Initially students were observed to work in a more data-application and information-gathering mode as they completed tasks that focused on teaching the ecology concepts and lab activities. For example, the second lesson of the unit included laboratory activities and there were minor design opportunities for students to choose in terms of selecting food samples to burn in the calorimetry lab or place in their compost bins. During the third observed lesson, the students presented their findings and what they learned with regards to energy from the activities. However, there was little discussion of the quality of evidence to support the students' claims or consideration of alternative reasons for their results. As students worked on their final products the level of rigor increased. Students were observed considering issues like feasibility, costs, and pros and cons of potential solutions as they developed their solutions to the driving question. The nature of discourse observed in the class was not consistently substantive, but also was observed to increase as the unit progressed. Initially, this was prompted by the teacher who would occasionally ask probing questions to draw out students' reasoning or evidence or prompt students to make broader ties to the driving question. When students presented their final products, this type of discourse and questioning began to come more from the students.

Multiple products and opportunities for feedback. The unit included multiple components for students to work on. Specifically these included the guiding packet that included ecology concepts and prompts for student reflections, the lab activities and accompanying presentations, a group quiz, and the final products and presentations. Over the course of the unit, students were mostly observed to revise their work by seeking feedback from the teacher. The students also had the opportunity to discuss their final products with their peers and get feedback prior to finalizing and presenting them to the class.

Other characteristics. Each student had a laptop to work on unit activities. These were mainly used for online research and to make presentations. For the lab activities, students had access to standard equipment such as balances and ring stands for the calorimetry lab and terrariums for the composting lab. With regards to interaction with outside experts, one group was observed to attempt to contact the school custodian for information related to their final product, but otherwise it was not observed.

Teacher as facilitator. Generally, the teacher facilitated learning by asking a mixture of recall questions on biology concepts and questions to lead students to specific concepts. Additionally, she asked some more probing questions to draw out students' reasoning or evidence or to prompt students to make ties to the driving question. For example, during the second observed lesson of the unit, the teacher had a drawing of a corn stalk on the board and asked students which parts had the most energy. As students responded, she asked them for the reasons behind their answers. During this discussion the teacher also asked more recall questions regarding plant cell parts and photosynthesis. Another strategy was class discussions and debriefing where students would share their small group work on assignments (e.g., ecology concepts in packet) with the class and the teacher would identify some points in common. For example, when the class discussed the carbon cycle, each group presented its own carbon cycle and the teacher asked them to remember a part of it in order to construct a whole class carbon cycle on the board. The teacher made limited use of direct instruction, but where it was observed there did not appear to be evidence of students' need for the information or a common misconception that spurred its use.

Assessment. There were multiple components in the unit to assess students regarding content and process. For example, there was a group quiz during the fourth lesson of the unit, but each student was given his or her own copy to complete. This was also true of the guiding packets. An example of a process assessment used in the unit was the peer evaluations that students completed on the final presentation days of the unit. In addition to individual assignments there were group assignments such as the lab presentation and final presentations. While this mix of assessments was noted, it was unclear how these components were assessed. For example, there was no rubric to give students' guidance on the final product and students were observed to be unclear on what was expected of them.

Final products. During the final product presentations, students proposed a variety of biofuels-based solutions to the driving question. Their presentations especially emphasized the efficiency aspect of the question in their solutions and they often incorporated school models in their proposals. As part of their presentation, students were observed to include the rationale for their proposed solutions. The audience, which consisted of their classmates, often asked questions related to feasibility and logistics of the proposed solutions.

Perceptions of Influences on Implementation of the PBL module.

Perceived barriers to Implementation of the PBL Unit. In the post-implementation interview, N. Robards' commented on challenges related to her teaching context such as the difference between her school's schedule and time allotted to activities in the unit as it had been designed, and her perception that the PBL unit did not sufficiently cover the ecology curriculum.

> "There were some things that I hadn't planned on in the trimester… there was a couple days I was absent, and I think that made it more difficult to kind of fit in the entire unit of the PBL.… my group kind of arranged it for more of a shorter class, maybe like 50

> minutes, and so, I think another challenge for me was try to make sure that the students had something to do for most of the 70 minutes. So then I had to scrunch up some days and some of the units."

> "It was very hard for me to figure out how to incorporate more standards in [the PBL unit] that were related specifically to the ecology unit. I've already taught photosynthesis and I've already taught cellular respiration and I've already taught some of these other things in other units.…there's a whole standards sections on interactions between parasitism and, you know, what's an abiotic factor, what's a biotic factor…. it was almost overwhelming to figure out how to incorporate those types of standards in when it was supposed to be focusing on just biofuels.…I could have spent probably another week on really expanding what are the nonliving things here, what are the living things here. But it almost I think would have gotten too dry… if I'm going to teach a wide variety of things within a unit, I like to address it in a lot of different ways versus just one driving question. So I think that was hard for me. Because now, this coming week, I'm still going have to teach the rest of the standards in the unit."

Perceived supports for Implementation of the PBL Unit. In the post-implementation interview, N. Robards identified supports related to the RGS program. These included materials developed at the workshop and interactions with RGS personnel.

> "A positive was just the how well our group [from the workshop] had done with organization. Like the notebook [guiding packet for the unit given to students] was just tremendously helpful….The calendar that we were supposed to make for the PBL unit over the summer that was really helpful, too.… I think [the project coordinator] was really available for any questions or concerns about the unit and, so I appreciated that, too."

Perceived Influence of the RGS program on Implementation of the PBL Unit. In the interview N. Robards commented on other supportive and beneficial aspects of the RGS program. These encompassed collaboration with other teachers, materials support, the influence of the workshop on her understanding of driving questions, the development of a PBL unit, and the workshop environment.

> "I like how they let us work within our groups to come up with our own way to first of all come up with a driving question. I think they did a really good job over the summer of developing what a driving question is and then allowing us to come up with our own driving question that we kind of talked about as a group. … I think they did a good job of taking us day by day through what we needed to complete. And then, in the end, you know, our products were all still different, which was good; I don't think we were limited with our thoughts or ideas. But I did appreciate the system of organization that they had. And I think that that then gave us some product that we could actually use in our classrooms."

> "I think everything's been great. I mean, they gave us materials to use and a budget for that and gave us [a] couple of weeks to develop something and definitely had every resource available to use then."

Regarding the online components, N. reported that she did not use them and that she encountered difficulties when she tried to use them. These included technical difficulties accessing the online components, scheduling conflicts with the virtual field trip, and lack of time to explore the resources. She suggested offering a more direct alternative to the online repository STEMEd Hub.

> "I actually didn't use any of those [online components]. …the virtual field trip, I wasn't there for….The STEMEd Hub thing…I had difficulties with passwords….I didn't have a whole lot of time to explore all the other resources available. I know I definitely did that over the summer, you know, a little bit when we had time. But just during the school year I didn't have [an] extensive amount of time to do that."

> "If they would've put things in pdf files that we can download to our computer in the summer and then have those resources [on STEMEd Hub] available to us, you know, as we're looking up our own files throughout the school year rather than go to a completely different link and have a password you have log in and then sort through everything on their website….I think it just makes it a lot quicker to access those things in the school year, you know."

Case 2: B. Lewis

Overview of case and unit. B. Lewis was an experienced science teacher, and reported that she had prior experience implementing PBL units prior to the one that was observed in this study. She chose to implement her PBL unit on enzymes in an honors introductory biology class. The unit focused on the following driving question: How can biological methods be effectively used to convert biomass to biofuels to meet our energy needs? Over the 19 days of lessons during which she was observed implementing the unit, students worked in small groups on an enzyme simulation involving toothpicks, online research to find information on enzymes used to convert biomass to biofuels, design and execution of experiments to study conditions that affect enzyme function, and a final product in which students developed ad campaigns in support of a mock referendum to fund research on the use of enzymes to make biofuels.

Implementation of PBL features.

Student-driven and student-centered instruction. The introductory activities of the unit were the same for all students and teacher-directed. The first was having students watch a video that speculated on the impacts of a sudden disappearance of the world's oil supply (Bambrick, Gallant, & Rowley, 2010) while students filled out a sheet of questions in response. This was followed by a hands-on activity in which students simulated the function of enzymes and the effects of various conditions using toothpicks. During this activity students had minor choices such as their role (e.g., recorder, timekeeper) in the simulation. After these common introductory activities, students had multiple opportunities to make major decisions about unit tasks. For example, after doing internet research on enzymes used to convert biomass to biofuels, the students designed their own experiments to test the conditions that affect enzyme function. They chose the enzymes, substrate materials, conditions to be changed, and designed or found the procedures to execute their experiments. For the final ad campaign project students could choose the components and format of their campaign.

Regarding student independence and responsibility, the students were observed starting unit tasks and working productively with little prompting form the teacher. Students were also observed to take responsibility for working on unit tasks outside of class and to divide tasks among themselves (sometimes with prompting from the teacher). For example, on two occasions students who were absent did as the teacher suggested and prepared lists of tasks to be completed by their teammates while they were away. This level of independence was particularly evident as students worked on their final products.

The teacher supported students by providing written handouts and rubrics throughout the unit. She gave additional verbal assistance by clarifying unit activities for students, giving timelines or showing students how to use some of the lab materials. Occasionally she was observed to do some tasks for students such as during the enzyme lab when she was observed to help with or take over preparing and testing the samples for some groups.

Content in context. There was a lack of integration between the science content of the unit, which included enzyme function, environmental science, and experimental design and real-life context. The observed pattern was that the lessons tended to emphasize either content or real-life contexts. For example, during the hands-on activities such as the enzyme simulation and the student-designed experiments, more of the focus was on the topic of enzymes and the conditions that affect them. The teacher would occasionally ask students to tie the hands-on activities to the topic of biofuels. Similarly, as students worked on their ad campaigns, they worked on tasks that were situated in a real-life context, but there was little tie between the task and the targeted science content that preceded it even though when the project was introduced the teacher encouraged student to use the lesson from their lab experiences in their campaigns.

Use of driving question. The teacher posted the driving question and unit objectives around the classroom. Occasionally, the teacher verbally reminded students of the driving question and prompted student to connect it to unit activities. For example, at the end of the third observed lesson of the unit in which students completed their data collection from the enzyme simulation, the teacher asked students to reflect on the relationship between the activity and the driving question. However, the posted reminders were the primary means of reminding students about the driving question. Additionally, the teacher included connection to the driving question in the evaluation of the final ad campaign project.

Student collaboration. After the first day of the unit, students worked in small groups throughout the unit. The composition of these groups was changed after the enzyme simulation because the teacher grouped students based on their interests. One of these groups seemed to consistently work productively, in terms of all members contributing to tasks and conferring with one another, but among other groups such cohesion was less consistently observed. At various times and in different groups, there were students who regularly were observed to not participate during activities and there were disagreements within groups regarding whether and how much students contributed to their teams' work. The teacher's primary means of facilitating student collaboration was through verbal guidelines such as reminding students to work in groups or to suggest ways to ensure participation such as assigning roles or suggesting ways to divide tasks, particularly in groups where collaboration issues arose. The teacher also included teamwork in part of the evaluation rubric for students' final products.

Substance and rigor. There were multiple opportunities for students to engage in rigorous, inquiry-oriented activities. The common enzyme simulation activity with toothpicks and the student-designed enzyme labs involved data interpretation as well as data collection. Additionally, the students had to synthesize lessons from these activities into written reports. For example, after both of these hands-on activities students worked in these groups to create whiteboards of their data and findings and the teacher had the groups review each others' boards and comment on them, an activity known as a "gallery walk" (Kolodner, et al., 2003, p. 516). However, the discourse associated with these activities did not reflect their apparent rigor. Much of the audible discourse was task-focused but very procedural. There seemed to be a greater emphasis on following procedures, collecting data, and formatting rather than making meaning, evaluating evidence, or discussing rationale. For example, during the feedback session where students had shared their toothpick simulation results and graphs, one group was told that their data was wrong. The students in this group countered that that no one else had shown the data in question, but there was no discussion of why the results might have come out differently than anticipated. One the more substantive side, in this same lesson, the discourse was more substantive when students were asked to relate their findings from the enzyme simulation to enzyme function.

Multiple products and opportunities for feedback. Multiple components comprised the unit. Specifically there were hands-on activities in the form of the enzyme simulation and student-designed labs, internet research on enzymes, and the final ad campaign project. Some of the revisions students made to their work were driven by direct feedback from the teacher. For example, as students were designing their own enzyme experiments, the teacher would point out flaws in students' procedures such as changing two variables instead of one or not clearly specifying their parameters. The teacher also made frequent use of the gallery walk strategy in order for students to give another feedback. For example during the student-designed enzyme experiment portion of the unit students did gallery walks of their draft procedures as well as their experimental results. Additionally, the student gave practice presentation of their ad campaigns prior to their final presentations.

Other characteristics. Throughout the unit students had access to devices such as desktop and laptop computers, tablet computers, and smart handheld devices. These were used for tasks like internet research and preparation of lab reports as well as in their final products to make video or audio components for their ad campaigns. Additionally for the enzyme experiments students had access to lab equipment such as water and ice baths and glucose testing materials. Regarding opportunities to work with non-classroom personnel, students attempted to contact outside experts for information about enzymes used for biofuels, but the outcome of these efforts was unclear. They also had some interaction with school library staff for troubleshooting help with technology.

Teacher as facilitator. Often the teacher, like the students, seemed to be focused on task completion during activities like labs and less on probing student reasoning. Where a more probing questioning strategy was observed it tended to occur in the form of the teacher responding to students' questions with more questions or suggesting topics for students research. For example, when a student asked about how to graph some of the data from the enzyme simulation the teacher asked the student how the two variables in question related to one another and to identify the independent variable. Another strategy that was observed on occasion was for students to share and discuss their findings with the class. For example, after students researched enzymes used to make biofuels online, the teacher included time for students to share what they found online.

The teacher made very little use of direct instruction. The brief instances that were observed appeared to be based on student need. For example, after the teacher looked at several students' graphs of their enzyme simulation data, the teacher called the class to attention and described how to properly graph data.

Assessment. The unit included multiple components to assess students individually and in groups. Some of the assessments included written reports on the hands-on activities, the enzyme research, and the final ad campaign projects. The teacher also used rubrics for some of these assignments, such as the enzyme research and ad campaign. The rubric for the ad campaign included assessment of process elements such as teamwork and presentation elements. However, while there was a blend of individual and group assessment as well as content and process assessment, the balance of content versus process was unclear.

Final products. For the ad campaign, students created a variety of final products. However these products tended to superficially address the driving question and there was little connection between these final products and the target science concepts on enzymes. Students' presentations were largely informational in that they mainly described the ad components and gave information about biofuels such as types of biofuels or the pros and cons of biofuels. There was little questioning from the audience. The audience for the presentations consisted of other students in the class and the district superintendent rather than potential stakeholders or experts.

Perceptions of Influences on Implementation of the PBL module

Perceived Barriers to Implementation of the PBL Unit. In the post-implementation interview B. Lewis commented regarding a problem with a piece of equipment, but she indicated that it was resolved. Her comments on ways that she would change the unit indicated that she was aware of an aspect of PBL that was not fully addressed when she implemented the unit. Specifically she commented on having students interact with research scientists to increase the relevance of the science content.

> "Challenge was…[the teacher] forgot how to use the glucose meters [for the student-designed enzyme experiments] and didn't read the directions. So they didn't work right the first day, but we managed through that and we got it figured out and we did the glucose meters and they worked really well."

> "I am probably going to have where the kids actually find a scientist to email and then let them email that scientist from my computer, so that they actually contact a scientist with what they're interested in.…Because I think that that puts a little more science into it and, and lets [students] see that yes, this actually is going on currently…. I think that actually having them converse with a scientist in the project that the enzyme and the breakdown that they're interested in might mean a little bit more to the students, and I'd like to try to implement that next year."

Perceived Supports for Implementation of the PBL Unit. In the post-implementation interview, B. Lewis identified supports related to the RGS program. These included making the PBL unit at the RGS workshop and the materials support from the program.

> "I think the planning in the summer really helped, being able to completely get the unit done. You know, sometimes when you go to summer workshops, you get things started, but you don't get them finished. So being able to have the unit finished and ready to go helped a lot in being able to implement it in the classroom. Also, the equipment, having the glucose meters and the glucose strips and the enzymes and stuff here helped as well."

Perceived Influence of the RGS Program on the Implementation of the PBL Unit. In the interview B. Lewis commented on other supportive and beneficial aspects of the RGS program. These encompassed enhanced knowledge of biofuels science from the talks by research scientists, getting ideas for activities that were included in the unit, and increased comfort for implementing the unit.

> "Like I said having the project completely done, having the time to work on it and get it completely done in the workshop with the group members. Also, I think having the background from the scientists was very important to help me feel more comfortable in teaching it….Plus, being able to go down to the lab and actually do the activities that we did. The lab activity with the glucose meters actually did also help. Because I would have never have thought to use glucose meters to test the breakdown [of biomass]."

> "As far as my learning in the biomass to biofuels, I actually learned a lot more about some of the different components they can take out of a plant and make different types of biofuel from, like the lignin versus the cellulose, and that kind of stuff. And that they [university researchers] are trying to get to where they can maybe actually make the biofuel directly that can be used directly without having to go through all the processing where it takes a lot more energy to make the biofuel than you actually get out of it. So I learned a lot about that in the research this summer."

Regarding the online components, B. reported that they had little impact on her implementation of the PBL unit and that she was unable to participate in the virtual field trip because it was not held during her class period. She indicated that she had accessed the STEMEd Hub repository to access her group's PBL website, and she stated that she hoped to participate in the virtual field trip in the future.

> "I really didn't go back to those [online resources]. I probably could have and should have, but I did not this time.…the only thing I did was go back to our weebly [website vehicle] that we posted on the STEMEd hub website was really all I went back to. Because that's the only place I have it [PBL unit] complete in total with all the stuff in it."

> "The virtual field trip that they did the other day. I'm going to try to do that in the spring when they do the next one. [Researcher asks for clarification] Yeah, it was a timing issue: It was the last day. It was not during my class hour. So trying to get the project finished up before Thanksgiving break.…The timing was just not good."

Case 3: F. Johnson

Overview of case and unit. F. Johnson was a relatively new science teacher, who had completed a course on PBL as part of her transition to teaching program and had implemented PBL units on other science topics. She attended the RGS workshop as a colleague and teammate of B. Lewis, but changed schools over the summer. Due to her new school's trimester schedule, she was able to her implement the PBL developed at the RGS workshop at least once prior to being observed for this study. She implemented her PBL unit in an introductory biology class. F. Johnson's PBL unit focused on the topic of enzymes and had the following driving question: How can biological methods be effectively used to convert biomass to biofuels to meet our energy needs? She was observed implementing the unit over the course of eleven class periods. During this time students worked in small groups on an enzyme simulation with toothpicks, a research and presentation project on enzymes used to make biofuels from biomass, a wet lab on enzymatic hydrolysis of sucrose that was accompanied by a packet of questions on enzymes, and a final ad campaign project to support research on enzymes for conversion of biomass to biofuels.

Implementation of PBL features.

Student-centered/student-driven instruction. Students tended to have limited input on the conduct of the hands-on activities (enzyme simulation and sucrose wet lab). For these activities, students were primarily responsible for completing the activities as directed and had minor choices such as the role they would take in the enzyme simulation (e.g., recorder, timer). Students had more input on the enzyme research project and ad campaign project, with the most choice on the ad campaign. For the enzyme research they could choose the topic to research and information resources. For the final project they could choose the enzyme and biofuel as well as the format of their ad campaign.

Students were observed to complete unit tasks once they were assigned and dividing tasks among themselves, often when prompted by the teacher. Towards the end of the unit, students were observed to take on more responsibility such as arranging to work on tasks outside of class and checking with each other that tasks were being completed. However, the level of students' independence was somewhat constrained by the teacher who would often step in as students worked to suggest ways for students to work more efficiently throughout the unit. For example, when students were doing the enzyme simulation with toothpicks the teacher was observed going to different groups and giving pointers on the procedure, suggesting how to divide roles for the different parts of the activity, and suggesting which parts to do next. In addition to these actions the teacher supported students by providing directions for activities, setting daily objectives, setting timelines and intermediate goals, and explaining the rubrics for assignments.

Content in context. There was some separation between the targeted science content of enzymes and the unit context of biofuels. As the students engaged in the activities leading up to the final ad campaign project, the emphasis was on concepts about enzymes and there was little emphasis on the context of biofuels. Similarly, as students worked on the final ad campaign project the real-life context of the task was not closely tied to the preceding science content.

Use of the driving question. The driving question was posted on the board each day of the unit. The teacher often tied the daily objectives to the driving question as well. The teacher was also occasionally observed to emphasize the driving question verbally by asking individual groups how their work tied to the driving question or raising the question in class. For example on the first day of the enzyme simulation at the start of the class the teacher asked students to think about how biology could help with energy challenges and at the end asked the class to think about how enzymes could help with the energy crisis. The teacher also included making connections to the driving question in the evaluation rubrics for the enzyme research and ad campaign assignments.

Student collaboration. Other than the first day of the unit when students watched an speculative video on the disappearance of the world's oil supply (Bambrick, et al., 2010), students worked in small groups throughout the unit. Overall the students appeared to work collaboratively, in these groups, particularly during the enzyme research and ad campaign projects. Students tended to work productively in their groups, divide tasks with prompting from the teacher as activities were introduced, and consult one another as they worked. There was one team of students that exhibited poor dynamics due to a domineering student's presence, but this group was an exception to the general pattern of behavior observed in the class. The teacher facilitated student collaboration by providing verbal guidelines such as encouraging students to assign roles and divide tasks within their groups and ensure that all group members were included in activities and decisions. Additionally, for the enzyme research assignment, the teacher included collaboration as part of the evaluation rubric.

Substance and rigor. The unit was largely focused on data collection and information gathering. There were some opportunities for data interpretation, such when students mad e whiteboards of their enzyme simulation results, including graphs, and presented them to the class. These discussions included some questions from the class about trends in their data and potential reasons for them, but such discussions occurred in a less sustained fashion. Much of the student discourse heard during the unit activities was task-focused but not necessarily substantive. During labs the focus was on following lab procedures and during the ad campaign project more discussion was observed regarding the design process rather than content of the ads. For example, the enzyme presentation and ad campaign components included presentations in which each group was required to include a question and answer session with their peers. During these sessions, students tended to ask factual recall questions about the information that was presented.

Multiple products and opportunities for feedback. The unit consisted of multiple components including the enzyme simulation, the research and presentation assignment on enzymes, the enzyme wet lab, and the ad campaign project. Students were often observed revising their work n response to direction from the teacher. The teacher also encouraged students to evaluate their work on the presentation and ad campaign projects against the rubrics that were provided at the start of those assignments. Prior to the final presentation each group had the opportunity to meet with the teacher, practice their presentations, and get feedback from her.

Other skills. With regards to classroom technology, students had access to smart handheld devices and desktop computers in a computer lab. These were used for research and in the creation of their ad campaigns (e.g., videos). Additionally the handheld devices were used as timers for the enzyme simulation and wet lab activities. In addition to these devices students had access to other lab equipment needed for the hands-on activities. Students did not interact with any outside adults during the project.

Teacher as facilitator. The teacher asked a mixture of question types. Primarily these were either designed to lead students to certain ideas or to get additional information/clarification from students during class discussions as well as some factual questions to prompt students to recall or identify information. Occasionally the teacher asked questions that required students to include evidence or a rationale in their response. Another strategy the teacher used was to put individual students' questions before the class to discuss. For example, on the next to last day of the unit the teacher started the lesson by asking students to come up with questions in preparation for the quiz. When a student asked what they needed to know the teacher returned the question by asking students to share what they knew about enzymes. In one particularly notable example of facilitation, after the students shared their findings from the enzyme simulation, the teacher led a class discussion and debriefing to identify shared ideas and concepts about enzymes. The teacher made limited use of direct instruction, but where it was observed there did not appear to be clear signs of student need. For example, when students conducted the lab on the enzymatic hydrolysis of sucrose they also had a packet of questions about enzymes to complete while they waited for parts of the lab to be ready for use.

Assessment. A variety of measures were used to assess students in their groups and individually. These assessments included elements to examine both content and process aspects of the unit. Some of the measures included the hands-on assignments, rubrics for the enzyme research and ad campaign projects, and a quiz on enzyme concepts.

Final products. Students' final products were varied in terms of the format of their ad campaigns and the types of biofuels they promoted, but they did not fully replicate real world products nor did they fully address the driving question. The products were generally informational in format (e.g., describing how a fuel was made) and where groups gave a rationale for their product it was given for the format rather than the content of the final product. There was little question and answer interaction with the audience of classmates as the products were presented. Instead the presenting groups tended to ask factual questions of the audience.

Perceptions of Influences on Implementation of the PBL module.

Perceived Barriers to Implementation. In the post-implementation interview F. Johnson's comments indicated that she perceived contextual barriers such as the school's trimester calendar, inadequate classroom space, and the need to pace herself with another biology teacher at the school as challenging influences on her implementation of the PBL unit. Additionally, she commented on her students' lack of familiarity with lab skills and her perception that the unit covered little biology content. Her comments on ways that she would change the unit indicated that she was aware of elements of PBL that were not fully addressed when she implemented the unit, such as more student-driven instruction and student collaboration.

> "One of the biggest challenges for me right now is that I'm on a trimester system, and I still have to cover all my standards, but this unit, ideally, would take about three to three and a half weeks. But because of the fact that we only have twelve weeks in a trimester it has to be implemented in a shorter time frame. So I had to cut a couple things out that we had originally planned to do."

> "I would like to adjust the sucrase [enzymatic hydrolysis of sucrose] lab to be a little bit more, inquiry based rather than just a guided lab…. due to time constraints, I cut it down to something that was very guided. And the fact that I don't have a lab, it's a problem. Because I just don't have the space to store everything. And the freshmen some of them are just not, they don't know laboratory techniques to begin with, so it's a safety issue trying to do too much."

> "Thinking towards next time I might honestly change when I'm doing [the PBL unit]. And possibly do this after students have learned a little bit more about proteins…. I'm not sure if that's necessarily the best place for it either. It's just, like I said before, a long unit that only covers like a very, very small part of one standard.…I might do some more exit tickets asking about group work, because I know group work's always a little problematic, trying to get everyone on board. My first hour class [the class observed during the study], there was one group that really did not work well together. I need to start figuring out, as a teacher, just in general with any group work, how to hold everybody accountable, but, also, to make sure everyone's on the same page."

Perceived Supports for Implementation. In the post-implementation interview, F. Johnson identified supports related to the RGS program, specifically the opportunity to collaborate with other teachers and make a unit

> "Being able to collaborate over the summer with a bunch of different individuals was great. We were able to, you know, come up with a really nice product by putting a lot of thoughts and ideas together."

> "The biggest thing probably would be just having everything ready. …[the fact that] our group had put it together rather than trying to look at a curriculum and figure out what that person who wrote it was trying to do was really nice. All the labs were there. I was able to refer back all the time to our website that we made. Everything was sort of—it was almost prepackaged, but it was our brains that did it, so it made sense….the kids got

> motivated. They were engaged….I didn't have a lot of lesson management problems, especially, like, in my second hour and previous trimesters because of it."

Perceived Influence of the RGS program. In the interview F. Johnson commented on other supportive and beneficial aspects of the RGS program. These included interactions with other teachers at the workshop as well as after the workshop, enhanced knowledge of biofuels science from the talks by research scientists, interactions with the RGS program personnel, and enhanced comfort with unfamiliar material.

> "The researchers were, were critical as well.… I still obviously do not know everything about what they're doing, but at least it gave me a better idea of what's going on and, and what's involved in the process of advanced biofuels.…And it helped me feel way more comfortable into implementing this unit even though I knew that were some areas that I probably wouldn't know everything about.…between that and being able to work with a really good group of individuals and putting our heads together, and then, I've actually seen all three of those individuals at conferences this year. So, we're still able to bounce ideas back off one another…the staff over the summer was great. [Workshop instructor name] was wonderful. There was a lot of help I think if there was only half the people available for this, it wouldn't have been nearly as well planned."

> "The support system has been wonderful. I get communication from everyone regularly…And I have all the email addresses from all my group members so I'm able to communicate with them as well."

Regarding the online components, F. reported that they had little impact on her implementation of the unit. She reported being unable to participate in the webinars and virtual field trips, and described barriers such as scheduling conflicts and issues at her school such as lack of support from technical staff and the school's policies regarding field trips. However, she acknowledged that the online resources were available and stated that she intended to make use of them.

> "Honestly, the two webinars, that were planned before, one of them was in the middle of a sporting event I was coaching at and then the other was in the middle of a vacation.…and then as far as the online components at school [virtual field trip], the one that you had more recently was on one of my testing days. So, it honestly hasn't made a huge difference, but I'd like to incorporate the next two into my teaching this year, and then if I'm invited to listen to any of the speakers next year I'd like to do that."

> "Part of the problem, with online components for school [virtual field trip] is also that our tech department's not very easy to communicate with, and they're not very willing to do those type of things….if I'm on prep it's really hard to get [students in a location to see the virtual field trip] they can only have field trips during a certain time, so that's sort of the problems I'm running into."

Cross-case summary. The cross-case analysis findings described in this section are based on an examination of the observation data from all of the participants. This provides a fuller description of teachers' implementation efforts and perceptions of their experiences.

Student centeredness and student-driven instruction. The extent to which instruction was observed to be student driven as reflected in student input on decision making in the unit varied across cases. The general observed pattern was for students to be given increasing choice over time, with students having more leeway on their final unit products. The most commonly observed strategy that was observed at some point was for students to choose from a teacher-set menu of options such as choosing from among teacher-designated formats for the final presentation or choosing among teacher-provided materials to design an enzyme experiment.

Another aspect of this feature was the level of student independence as observed in the extent to which students were observed to be responsible for and capable of successfully completing unit tasks. Again, a range of behaviors was observed. At the high end, students were observed to start unit tasks on their own, stay on task, and make their own arrangements to divide responsibility for task completion including work outside of class. In these cases, the teachers tended to support students by suggesting timelines or intermediate tasks to complete or by clarifying unit tasks when students were unclear. It was more frequently observed for students to take on less responsibility for unit tasks. In these cases teachers were observed to step in to suggest ways for students to work more efficiently, to check that students had divided tasks or to ensure that students were on task, and students were responsible for working on tasks after being given overviews or guidelines by the teacher. Across cases teachers were observed to provide verbal guidelines or additional information to supplement written guidelines such as instructional sheets, rubrics, and written timelines. In spite of such supports, in some cases there was a lack of student clarity with regards to expectations for unit tasks, particularly for the final product. As this was observed with equal frequency in classes both with and without guiding final project rubrics, it suggests that some other means of communicating expectations may have been needed.

Content in context. Situating the targeted science content in authentic contexts appeared to be a challenging task for teachers. Two major issues were noted. First, content was not fully integrated with the context of biofuels. In these cases, the two aspects tended to be treated somewhat separately such that the instructional focus of the observed lessons was more on the targeted content and the ties to real world context via purposeful use of the driving questions were not emphasized. Second, the real world context was unclear in some cases. There were classes where teachers frequently mixed issues related to nutrition into units that were ostensibly about biofuels. In classes where this feature of PBL was implemented with more fidelity, teachers were observed to use strategies such as regularly asking students to make connections between the unit activities and the project context or driving question or asking students to make connections between the unit and their future lives and decisions.

Use of driving question. Intertwined with the issue of situating targeted content on context is the teachers' use of the driving question as a focal point for the unit. On the positive side, five of the seven teachers were observed to regularly display the driving question in the classroom or on unit handouts. Some were also observed to take further steps such as including relationship to the driving question as part of the assessment of students' final products and tying the question to daily objectives. Fewer of the participants made consistent efforts beyond such displays to use the driving question as a focal point to contextualize unit activities through strategies such as emphasizing the question during class discussions or regularly asking students to make connections between the unit activities and the driving question. We suspect that this is linked to the limitations observed with regards to situating the units' science content in context. It is notable that in three of the cases where participants included addressing the driving question as part of their assessment of students' final products, the students' final products were observed to do this only superficially. As these were cases where the unit was common to the teachers it suggests a possible issue within the unit.

Student collaboration. In six of the seven cases, students worked in small groups throughout the unit. However the extent to which these groups were collaborative in nature as reflected by all students contributing to tasks and conferring with one another was not as evident. Issues such as lack of participation and conflict within groups was observed in five cases. The main facilitation strategy that teachers employed was the use of guidelines, often verbal ones, such as suggesting how to divide tasks and encouraging teamwork. Three teachers were observed to include student collaboration as part of their assessment of student work through assignment rubrics as group process documents. However other strategies such as having students develop their own guidelines to work in groups or regular and early discussions of how to effectively work in teams were not observed.

Substance and rigor. All of the teachers implemented units that lasted at least the length of a typical school week (five days). However the degree to which they reflected rigor and substantive work was lower. In general there seemed to be a greater emphasis on information seeking and data collection activities than on activities that involved more rigor such as evaluation and interpretation. This is not to claim that students never had such opportunities. All of the teachers had students engage in laboratory or hands-on activities and in most cases these included some space for elements of experimental design such as choosing part of corn to test with a standard procedure to more involved activities where students identified their own variables to test and decided how to test them. Additionally, most of the participants provided opportunities for students to interpret their collected data and share their findings with their peers or included data analysis in the form of graphing or calculations as part of the unit. However, these activities often seemed to occur in a more perfunctory fashion with less in-depth discussion of the meaning of data or quality of evidence. With regards to the nature of discourse heard throughout the units it ranged from cases where the majority of audible discourse was lacking in substance because it was largely off task or focused on task completion with a heavy emphasis on following procedures or a blend of procedural task without some more substantive evidence focused discussion to a case where the rigor and substance of discourse increased over time as the unit progressed.

Multiple products and multiple opportunities for feedback. Generally the teachers included multiple components for students to complete in their units. In all of the cases it was observed that students often made revisions to their work during the units based on comments or suggestions from the teacher. However in five of the seven cases, students also were given opportunities to revise their work, particularly on their final products, by other means such as self-evaluation against rubrics, or practice presentations where they got peer/teacher feedback or peer discussions.

Other characteristics. In all of the cases students were observed to have access to technology resources such as computers, tablets, and other devices at some point during the units whether through school computer labs, a set of materials in the classroom, or individual student laptops. Additionally students had access to lab equipment (e.g., glassware) to do the hands-on activities included in the units. However the purposefulness of the activities or equipment where these activities were used was sometimes unclear. For example, in three cases activities that appeared to have no clear purpose with regards to addressing the driving question or central topic were observed. In other classes some students did not take advantage of the available technology resources to enhance the quality of their work or the technology proved to be a distraction. Finally, in none of these cases were students observed to interact with non-classroom personnel who had expertise in the topics of the units. Rather, students interacted with other school personnel such as school librarians.

Teacher as facilitator. Teachers tended to limit their use of direct instruction, which is appropriate for PBL. However, where it was observed, direct instruction tended to occur without clear signs of need from students. Teachers used a mix of questioning strategies, but often the questions were recall-focused, asked to get follow-up responses from students, or were used to lead students to specific concepts. Occasionally, some teachers asked more probing questions to prompt students to support their answers with evidence or to make broader connections between concepts. Another instructional strategy observed in multiple cases was having students share out in discussion such as after doing online research or debriefing at the start or end of a lesson to identify what was learned.

Assessment. While teachers were observed to use multiple components in the units to assess student learning and progress, there was still some room for improvement. The majority of teachers incorporated assessments for both group and individual student progress. It was often unclear how different elements such as content and process elements (e.g., collaboration) were being assessed. In two cases it was unclear how students' final products were assessed because of the absence of rubrics.

Final products. All but one the observed units required students to create and present a final product in response to the driving question. In all of these cases, the final presentations were done in the context of a classroom audience of non-experts or non-stakeholders. A common deviation that arose was that students' final products often did not fully address the driving question even if students' final products were varied in terms of their format and/or content. Additionally, most of the observed final presentations were more informational in nature. In the 2 cases where more robust presenter-audience interactions were observed during the presentations, only one focused on the content of the presentations rather than the format.

Overall Perceptions of Influences on PBL Implementation.

Perceived barriers to implementation of the PBL units. Teachers reported the following barriers to implementation: teachers' perceptions of their students or students' abilities, concerns about content coverage, elements of PBL that teachers could not fully address during implementation, challenges in teachers' individual situations or contexts, challenges related to the objectives in the PBL units, and trouble with equipment.

Similar to F. Johnson, two other teachers made comments indicating that they perceived limitations in their students or students' abilities that were challenging or hindering influences on their implementation of the PBL unit. These findings accord with the results reported by Marx and colleagues' (1994) case study of four teachers and the content-focused teacher in Rogers and colleagues' (2011) study.

> "I like the project, not a big fan of the class, but I like the project. I think it would've worked a whole lot better in probably a little more upper level class or if I had a different mix of kids." (E. Davies)

As illustrated by F. Johnson and N. Robards, three teachers made comments that suggested that they had concerns about the amount of science content addressed in the units. These included comments regarding the limited standards addressed by the unit or plans to include more science content in the unit. Other researchers have noted that coverage of content is a common concern for teachers when they teach using PBL (Combs, 2008; Ladewski, et al., 1994; Lee & Bae, 2008; Marx, et al., 1994; Rogers, et al., 2011; Rosenfeld, et al., n.d.).

Examination of teachers' comments on challenges experienced during implementation and changes they would make in future implementations indicated that they were aware of elements of PBL that were not fully addressed in their units. Similar to F. Johnson and B. Lewis, these five teachers commented on issues such as strategies to improve student collaboration, addressing the driving question, having students engage in more investigations, making science content relevant, and balancing student choice while ensuring students make a variety of final products.

> "I might have options for groups, but not allow any group in the same classroom to use the same option. You didn't have it in your class that you watched, but there were some classes that tried to do like 5 groups do a poster, like that's boring, and it's all kind of similar." (T. Morris)

Other challenges that teachers encountered were more contextual such as fitting their units into their particular school schedules or situations, or breaks occurring as they implemented their units, a finding that accords with the work of Krajcik and colleagues (1994) and Ladewski and colleagues (1994). Four teachers, including F. Johnson and N. Robards, commented on these types of challenges.

Two teachers described challenges related to their unit objectives, and two teachers, including B. Lewis, reported trouble with equipment.

> "Having objectives a lot more clearly defined.…I was really worried about that with this project because I really didn't know until we were going to where our objectives were going to go." (S. Thompson)

> "We got a solar car, and we couldn't get that thing to work worth a dime, and they [students] were very frustrated with it. They would pick it up and it would work; you could see it. It just didn't have enough energy to move the car." (S. Thompson)

Perceived supports for implementation of the PBL units. Based on the post-implementation interviews, the following perceived supports for teachers' implementation of their PBL unit were identified: supports related to the RGS program and supports related to teachers' individual contexts.

As illustrated in the cases of N. Robards, F. Johnson, and B. Lewis, the majority of participants identified supports related to the RGS program. When asked to identify supports for implementation, five teachers commented on benefits from the program including experiences at the workshop, materials provided by the program, supportive interactions with RGS personnel, and enhancement of content knowledge.

> "Well that class definitely helped me a lot I think because I didn't know too much about biofuels." (E. Davies)

Two teachers identified more context-specific supports. These included working at a school with a teacher who had participated in the first RGS workshop and using easily obtained materials for activities.

> "D. Collins [mentor teacher at workshop] was a big help making the project, because if I had questions I would go straight over to D's room when we were at [university name]. And the fact that I taught with D., when I had questions about how to implement some stuff in the calorimeter lab…I just went over and popped my head in"

> "All of it [material used in unit] was pretty much commonly available material.…Cans and soybeans and corn and it's things that we have that you literally can go to the shelf and get." (R. Jefferson)

Perceived influence of the RGS program on implementation of the PBL units. Regarding the influence of the RGS program teachers identified aspects that supported their implementation efforts as well as program elements that they perceived as having little influence.

As illustrated in the cases of N. Robards, B. Lewis, and F. Johnson, teachers identified supportive program elements such as the ability to collaborate and interact with other teachers both during and after the workshop, enhanced content knowledge and comfort for implementation from the research scientists' presentations, materials support, supportive interactions with RGS personnel, enhanced understanding of PBL or elements of PBL, development of the PBL units and elements of the PBL units, and the supportive workshop environment. Additionally, two teachers reported using PBL strategies outside of the observed PBL unit, a strategy that has been noted by other researchers (Ertmer & Simons, 2006; Lee & Bae, 2008; Rosenfeld, et al., n.d.).

> "Using those types of instructional devices, those driving questions to keep things going and tie things together. I had been trying to use that for every unit that I do. And, creating need-to-knows through assignments that engage students so that then they are wanting to learn or in a situation where by me presenting something it's helping solve a problem for them as opposed to just giving them more information to memorize." (T. Morris)

Based on comments in the interviews, the participants perceived the online components (i.e., webinars, virtual field trips, STEMEd Hub) as having little influence on their implementation efforts. All of the teachers reported not using some of the online components or explicitly stated that they had little impact. They also described a variety of barriers to using the online resources including scheduling conflicts with the webinars and virtual field trips, difficulties accessing material, simply being too busy, and school policies. However four teachers, including B. Lewis reported some use of the online resources, and they made comments indicating that they had attempted to or intended to use them. Two teachers suggested more direct alternative to the online resources, such as in-person meetings or direct email of resources instead of STEMEd Hub. Finally, some of teachers' comments suggested that they were confused or unsure of the nature of the online resources. In four cases, the online resources were referred to by the wrong name or teachers indicated that they were unsure of what was available through them.

Discussion

Aspects of each feature of PBL were observed consistently across the observed units. Teachers implemented their units so that students were able to work in teams with their peers and develop and present solutions to real world challenges that focused on science concepts. Furthermore, students were provided with opportunities to engage in hands-on and investigative activities, including some data interpretation or analysis, through multiple assignments leading up to the presentation of their final products. Teachers were observed to make limited use of direct instructional strategies and incorporated a variety of assessments to examine students' content knowledge and process skills. These are positive findings since these aspects of PBL were modeled or discussed at the 2012 RGS summer workshop.

In spite of teachers' efforts to implement some features of PBL, as they were defined for this study, were not observed as consistently. Students had little interaction with outside experts or audiences. While students were placed in groups to complete the projects, they often needed assistance from their teachers to work productively, yet the primary observed strategy employed by teachers to facilitate collaboration was often limited to telling students to cooperate. Other researchers (Ertmer & Simons, 2006; Ladewski, et al., 1994; Marx, et al., 1994) have noted that facilitating student collaboration can be a challenge for teachers when they implement PBL units. Finally, the use of the PBL units as vehicles for deep learning of science content embedded in real-world contexts was not evident in most cases. This can be observed in the lack of consistent meaning-making activities and evidence-focused discourse as well as the frequency with which students were observed to create final products that had little connection to the driving questions of the units. Other researchers have also observed or commented on this type of outcome as a potential pitfall when teachers implement PBL (Ertmer& Simons, 2006; Rosenfeld, et al., n.d.).

Based on the observations from the collective case study, this cohort of RGS participants implemented the PBL units they developed at the workshop with partial fidelity of implementation to the instructional features of PBL identified for this study. While there were individual differences in how teachers implemented their PBL units, most of the PBL features were implemented in a less than optimal manner where elements of best practice were present but not consistently implemented. Features that seemed to be particularly difficult to implement fully were those that related to making units a vehicle for meaningful learning such as integration of targeted science content within the real-world context of biofuels science, teachers fully taking on the role of facilitators, and consistently implementing the units in an investigative rather than procedural fashion. This study does not account for teachers' prior practices and background knowledge, so their observed practices cannot be fully attributed to their experiences with the RGS program.

The lack of integration between the units' STEM content and the context of biofuels may be rooted in the workshop itself. First, at the workshop development of teachers' understanding of the PBL pedagogy tended to be emphasized over building their understanding of biofuels science. There were no biofuels-focused activities, outside of research talks by scientists from the biofuels research program, until the second week of the workshop. The time devoted to conducting these activities, including making meaning from them, tended to be quite limited. This lack of emphasis may have led to gaps in the teachers' knowledge that could have limited their ability to integrate their core science content with the topic of biofuels once they were in their own classrooms. This limitation of the workshop was also noted by the program's external evaluator (Laursen, 2013). In accordance with the evaluator's recommendations, the workshop has continued to be revised in order to more clearly identify learning objectives related to the research content for teachers, with a particular focus on concepts that are accessible to teachers from diverse content backgrounds. This lesson from the RGS program has implications for other professional development programs that seek to enhance teachers' content knowledge as recommended by the literature on effective professional development (Blank, de las Alas, & Smith, 2008; Desimone, Porter, Garet,Yoon, & Birman, 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001; Loucks-Horseley, Stiles, Mundry, Love, & Hewson, 2010).

It is more perplexing to develop an explanation for why aspects of PBL related to teachers' roles as facilitators of student learning and collaboration were not executed as anticipated. At the workshop there were multiple discussions of these issues. The topics of how to ensure content learning, the role of "traditional" instructional strategies in PBL, how to facilitate learning and student agency, how to facilitate student collaboration besides telling, ways to bring in outside experts and outside audiences for students presentations were discussed during morning debriefings and included in participants' own presentations on the elements of PBL. Finally when teachers presented their own PBL units, they explicitly identified strategies to address these elements, but these intentions did not fully translate into practice. It has been suggested that teachers can practice and develop their skills as facilitators by using PBL strategies during their regular classroom activities (Ertmer& Simons, 2006; Lee & Bae, 2008; Rosenfeld, et al., n.d.). Perhaps the workshop should provide opportunities for teachers to practice facilitating mini-lessons as well as teaching their full units, in order to move beyond discussion of such strategies.

Another possible explanation for the difference between what was observed in classroom and what was discussed at the workshop may lie in the distinction between discussing pedagogical strategies and explicitly modeling them. When the first author examined her notes from the workshop, she was able to identify instances where the facilitators did use strategies such as direct instruction on an as needed basis. However, it was not clear to her if they made the teachers aware that they were using these strategies. She briefly met with two of the facilitators to discuss this speculation with them. While they found it difficult to recall whether they had explicitly drawn teachers' attention to the fact that they were modeling particular strategies during the cohort 2 workshop, they noted that beginning with the cohort 2 workshop they had made more efforts to point out when they were modeling a strategy and had been continuing to do so in subsequent workshops.

Since this study does not compare teachers' implemented units against the units they planned at the workshop, it is possible that lack of fidelity to the structural critical components (Century, et al., 2010) of teachers' units may be behind some of the implementation issues that were observed. This is very likely for teachers who did not implement the units they designed, but it could have also have affected teachers who did attempt to implement the units they made. Teachers commented on excluding or modifying activities that were originally part of units. These decisions to modify the units tended to be in response to challenges they encountered once they were in their school contexts (e.g., N. Robards and F. Johnson's comments on challenges associated with the trimester schedule).

The teachers' comments regarding their perceptions of influences on their implementation also give insight into the effectiveness of the workshop. Even though the teachers perceived benefits from the program such as enhanced understanding of PBL and biofuels content, the data from the observations regarding the lack of integration of STEM content into the context of biofuels and the incomplete implementation of elements of PBL, suggest otherwise. Additionally, the teachers made comments indicating that they were aware that some elements of PBL were not fully implemented.

Participants' comments regarding the importance of collaborating with each other and interacting with RGS personnel suggests a program element to further develop as a support for teachers' efforts to implement PBL. The importance of collaboration between teachers and professional development providers has been identified as an important support mechanism for PBL and other reform-oriented instructional strategies (Anderson, 1995; Ertmer& Simons, 2006; Goodnough & Cashion, 2006; Krajcik, et al., 1994; Ladewski, et al., 1994). Thus, it is critical to find a means to maintain the collaborative aspect once teachers return to their own schools. This is the intent of the online resources proffered by RGS. However, participants' comments suggest that these resources did not serve as a meaningful support mechanism for their implementation efforts. Their comments suggested a preference for other means such as email or face-to-face meetings. Other researchers have posited that online mechanisms can be used to support teacher professional development, but also noted that these mechanisms are challenging to develop (Barab, MaKinster, & Scheckler, 2003; Shea & Shanahan, 2011). The findings from this study highlight this point. Further work is needed to find ways to make the online resources more useful to the RGS participants. Barab, MaKinster, and Scheckler (2003) noted that online communities are more successful when they are grounded in face to face interactions and teachers can participate in the design and development of online communities. This second element may be key to establishing buy-in from the RGS participants regarding the online resources.

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Appendix A

Post-Implementation Interview

1) Please tell me about your experience implementing this PBL unit, particularly in terms of things that supported or enhanced your implementation as well as challenges you faced.
    a. What supported or enhanced your implementation of the unit? (prompt if not mentioned)
    b. What challenges or difficulties did you face as you implemented the unit? (prompt if not mentioned)
2) What impact do you think the unit had on your students and how could you tell?
    a. How could you tell? (prompt if not mentioned)
3) What aspects of the Research Goes to School summer professional development program were particularly influential as you implemented the unit?
4) The program includes online components, namely STEMEdHub, webinars, and virtual field trips. How did they affect your implementation of the PBL unit?
5) Now that you have implemented this PBL unit, what changes would you make to your PBL unit?
6) Are there any other types of support from the Research Goes to School program that you feel need to be included to help you implement this unit?
7) What did you learn as a result of implementing this PBL unit specifically regarding PBL and biomass to biofuels?
    a. What did you learn about PBL? (prompt if not mentioned)
    b. What did you learn about biomass to biofuels? (prompt if not mentioned)
8) In what ways did you incorporate biofuels concepts into this unit?
9) How would you describe your confidence level as you implemented this PBL unit?
10) Is there anything else you would like to share about your experience?

Appendix B
Observation Analysis Rubric

	Score			Source[1]
Indicator	3	2	1	
Student Role: Student reflection and metacognition	Students monitor learning and ask questions of themselves and others (e.g, students record their thoughts and questions about the problem/project in a journal or notebook but entries are based on students thoughts about the project/problem as it unfolds)	Students monitor learning and ask questions of themselves and others (e.g. students record their thoughts and questions about the problem/project in a journal or notebook but entries are based on students thoughts about the project/problem as it unfolds)	Students monitor their learning and use prompts from teacher to question their learning (e.g. students keep a journal or notebook in which they record their responses to teacher prompts). Students monitor their understanding and progress in answering the driving question through teacher guidance.	Combs, 2008; Fouts, Brown, & Thieman, 2002[2;] Supovitz & Turner, 2000; Savery, 2009
Student Role: Student voice and choice	Students have a voice and choice in major decisions that affect the conduct and content of the product (ex: topic to be studied based on the driving question/problem to be investigated, resources and technology used, product to be created). Students have increasing ownership or choice over the course of the unit. Students design and implement their own investigations for major components of the project.	Parameters and desired outcomes are set by teacher. Students are given limited opportunities to express voice and choice on issues (ex: division of labor and group members). Students have limited ownership or choice throughout the unit. Students exclusively choose from a menu of options provided by the teacher. Students design or implement their own investigation for a minor piece of the project.	All parameters of the inquiry (due dates, outcomes, expectations, resources to be used) are established by the teacher; Students are not given opportunities to express voice and choice regarding decisions that affect the conduct or content of the project. Students have no opportunities to design or implement their own investigations.	BIE, 2009b, 2010; Galileo Educational Network (GEN), 2002-2005; Savery & Duffy 1995

	Score			Source[1]
Indicator	3	2	1	
Student Role: Independent student work	Students have several opportunities to take responsibility and work independently from the teacher. Students show signs of developing organizational and self-management skills as they complete the project (e.g. as a group they set their own deadlines to meet project goals and outcomes and check on each other to ensure that each member contributes to the project).	Students have a few opportunities to take responsibility and work independently from the teacher. Milestones and organizational strategies are provided by for student self-monitoring (e.g. hard timelines, hard intermediate due dates/ deadlines).	Students are expected to work too much on their own without guidance from teacher or they are given no opportunities to work on their own.	BIE, 2010; Supovitz & Turner, 2000
Student Role: Student engagement in extended inquiry	The inquiry extends over several class periods (a week or more in duration).	The inquiry extends over more than 1 or 2 class periods.	The inquiry or project is not extended over time and can be completed in 1 or 2 class periods.	BIE, 2010; GEN, 2002-2005; Supovitz & Turner, 2000
Student Role: Student engagement in rigorous inquiry	Students are engaged in a process of academically rigorous inquiry (posing questions, deciding what constitutes evidence, collecting and interpreting data, evaluating solutions or products) Students consider alternatives and/or multiple ways to investigate and solve the problem presented by the driving question	Students are engaged in superficial inquiry (e.g. the main task is gathering information or data). Students acquire and apply knowledge but don't build it.	Students are engaged in an activity or applied learning task.	BIE, 2010; GEN, 2002-2005; Supovitz & Turner, 2000; Norton and Wiburg, 2003
Student Role: Student collaboration	Students work in collaborative teams in which each member is necessary and contributes in order to ensure the group's success.	Students work in cooperative groups (more division of labor)	Students work individually for most of the project	BIE, 2010; Johnson, Johnson, & Smith, 1998

	Score			Source[1]
Indicator	3	2	1	
Student Role: Student-driven discourse[3]	The majority of classroom discourse is driven by students and occurs between students	Teacher determines topics for discussion but then has students discuss among themselves	The majority of classroom discourse is driven by teacher and occurs between teacher and students	BIE, 2009b; Piburn et al., 2000; Yezierski & Herrington[4], 2011
Student Role: Student engagement in substantive conversation	Students and students or students and teacher frequently engage in substantive conversation that builds knowledge and develops critical thinking (e.g. generation of hypotheses, sharing and comparing of results, discussion of conclusions) in a sustained way	Students and students or students and teacher engage in conversation that sometimes focuses on knowledge building and critical thinking but not in a sustained way	Students and students or students and teacher do not or minimally engage in conversation that builds knowledge or develops critical thinking. Talk is largely focused on task completion and/or following procedures with little discussion of content or rationale.	BIE, 2010; Fouts, Brown, & Thieman, 2002; Savery, 2009; Savery & Duffy 1995
Student Role: Revision of student work in response to feedback from peers and teacher	Students rethink and revise work based on data, self-evaluation, and/or constructive feedback from peers/teacher	Students revise or re-do work in response to evaluation from teacher that tells them what to do next or students revise/re-do based on a correct/incorrect notice from teacher	Students do not rethink/ revise work based on data, etc. The only expectation for completion is handing in the assignment	Ertmer & Simons, 2006; Fouts, Brown, & Thieman, 2002; GEN, 2002-2005; Norton & Wiburg 2003

	Score			Source[1]
Indicator	3	2	1	
Student Role: Student creation of unique products in response to the driving question	The major culminating products answer the driving question and result in students creating a variety of possible solutions or products. These products replicate the work done in a real world context (e.g. a presentation with set of recommendations for a review committee)	The major products address the driving question but do not replicate work that is done in a real world context (e.g. an informational report or presentation). The products are highly similar (e.g. several shoebox dioramas) OR Students make a variety of products, but these products superficially address the driving question.	The major products do not address the driving question or there is no major product only a series of smaller assignments. All of the final products are the same (e.g everyone uses the same kit to make a model rocket).	BIE, 2009a, 2010; Norton & Wiburg, 2003; Savery, 2006, 2009; Savery &Duffy 1995
Student Role: Student defense of product: Content	Students present and provide detailed defense of product (describing and defending inquiry process and decisions made) to audience other than teacher and classmates through a presentation or exhibition	Students present their products during an informational question and answer session. (Ex: The Q&A is more superficial and based on topics covered in the unit like vocabulary)	Students do not present or defend products	BIE, 2010; GEN, 2002-2005; Norton and Wiburg 2003; Prensky 2010; Savery, 2009
Student Role: Student defense of product: Audience	Students present product to a targeted audience, preferably stakeholders or experts.	Students present their products to a classroom audience (e.g., teacher and classmates, non-stakeholder administrators)	The product is given to the teacher only	BIE, 2009; GEN, 2002-2005; Norton and Wiburg 2003; Prensky 2010; Savery, 2009
Teacher Role: Teacher use of direct content instruction	Teacher uses direct content instruction in response to signs of students' need for information that cannot be found otherwise.	Teacher provides some direct content instruction regardless of signs of students' need or ability to find the information themselves	Teacher provides direct content instruction for majority of unit	BIE, 2003; Combs, 2008; Ertmer & Simons, 2006; Kolodner et al., 2003;

	Score			Source[1]
Indicator	3	2	1	
Teacher Role: Teacher facilitation of student content learning	Teacher asks students open-ended questions that probe conceptual understanding and lead to sensemaking and guides students to help them develop learning goals and construct knowledge. Teacher requires students to supply evidence to support their claims. Teacher asks questions that guide students to consider alternative explanations or solutions to problems. Teacher includes time to debrief as a class in order to help common understanding of key concepts.	Teacher asks questions that lead students to knowledge and either outlines or helps students outline learning goals and strategies. Teacher occasionally asks questions that require students to provide a rule or reason to support their claims. Teacher encourages students to consider alternative explanations and solutions. Teacher encourages students to look for more information. Small groups share, but there is no effort to debrief and identify common understanding of key concepts.	Teacher asks closed-ended questions that focus on discrete skills or content and demonstrates problem-solving process through the use of small problems. Teacher focuses students' attention on a single explanation or solution. There is little or no debriefing to ensure common understanding of key concepts.	Combs, 2008; Ertmer &Simons, 2006; Fouts, Brown, & Thieman, 2002; Hmelo-Silver and Barrows 2005,2006; Savery,2006, 2009; Savery & Duffy, 1995; Supovitz & Turner, 2000
Teacher Role: Teacher facilitation of student metacognition	Teacher models questioning to help students in their self-questioning activities	Teacher uses prompts to engage students in self-questioning.	Teacher does not encourage student metacognition or only has students reflect on project at the end	Combs, 2008; Ertmer & Simons, 2006; Fouts, Brown, & Thieman, 2002

	Score			Source[1]
Indicator	3	2	1	
Teacher Role: Teacher facilitation of student collaboration	Teacher regularly encourages students to explain concepts to one another. Teacher arranges seating to facilitate student discussion and small group work. Teacher provides prompts to help students determine rules for how to work together as a team (e.g. contract with prompts for students to lay ground rules of teamwork).Teacher uses non-directive strategies to ensure that all group members are engaged in PBL unit (e.g. asking students, especially quiet ones, in a group to summarize). Teacher includes time for students to process how they worked together as a group	Teacher provides a list of guidelines or rules for students to work together. Teacher arranges seating to facilitate student discussion and small group work. Teacher frequently uses directing strategies to check for student participation (e.g. telling students to work together) or teacher frequently steps in to ask if all students are being included in group decisions or work or suggests ways for students to work together effectively.	Teacher mostly has students work individually. Teacher arranges seating to focus class' attention on the teacher or does not arrange seating to facilitate student discussion and small group work. or puts students in groups and makes no effort to help students work together.	BIE, 2009c; Ertmer & Simons, 2006; Hmelo-Silver & Barrows, 2006,2008; Savery, 2009; Supovitz & Turner, 2000;
Teacher Role: Teacher's use of scaffolding	Teacher provides appropriate scaffolds so that students have the opportunity to work on the majority of the project independently	Teacher provides scaffolds throughout the project so that the students have the opportunity to work on the project somewhat independently	Teacher provides too few scaffolds so that students are unable to complete project or teacher does not allow students to work independently	BIE, 2003, 2009c, 2010; Ertmer & Simons, 2006; Hmelo-Silver & Barrows, 2006,2008; Savery, 2009; Savery &Duffy 1995
Teacher Role: Organization of activities around a driving question	Teacher presents students with driving question and regularly focuses class on the driving question throughout the unit	Teacher presents driving question and refers back to it but does not use it to focus the class activities	The driving question is not presented or is presented only once or twice during the unit (e.g. at beginning or end)	BIE, 2009a, 2010; Ertmer & Simons, 2006

	Score			Source[1]
Indicator	3	2	1	
Teacher Role: Assessment of student progress	Assessment is both group and individual, consists of multiple measures and is evenly balanced between content and process.	Assessment consists of at least two measures and is both group and individual. The focus is primarily on content or process.	Assessment is only group or individual and focused only on process (ability to complete task) or content understanding and consists of a single measure (e.g. test, quiz, informal questioning)	BIE,2009a, 2010; Savery& Duffy 1995; Supovitz & Turner, 2000
Teacher Role: Use of entry events	There is an entry event that generates questions and establishes a need to know and presents the problem to students in a authentic manner	The entry event is present but does not establish a need to know or generate student questions.	There is no entry event. The problem is directly presented to the students.	BIE, 2009a, 2010; Savery & Duffy , 1995
Teacher Role: Focus of the PBL on content in context	The teacher focuses the PBL unit on STEM content and contextualizes the problem by grounding it in life and work beyond the school so that it is relevant to students	The teacher presents a problem that related to the world outside the school; The unit includes STEM content, but it is not well-integrated into a real-world context.	The project involves a teacher structured problem that is framed directly from curriculum outcomes and no real world context; The content to be addressed is not particularly relevant or meaningful to students or the unit includes little STEM content	BIE, 2010; GEN, 2002-2005; Norton & Wiburg (2003); Savery, 2009; Savery & Duffy, 1995
Resources: Use of outside experts	Students work collaboratively with outside experts who have relevant expertise and experiences in order to develop students develop a solution to the problem they are trying to solve	Students have limited access to outside experts in a limited form such as guest speakers or for interviews. The available experts may not have expertise or experience that can help students develop a solution to their problem.	Students have limited or no access to outside experts. They primarily receive information from the teacher or teacher-designated resources.	GEN, 2002-2005

	Score			Source[1]
Indicator	3	2	1	
Resources: Use of technology and material resources	The project incorporates technology or equipment on an as needed basis in order to enhance the quality of students' skills, engagement, and work. Technology use is student driven.	Some technology or equipment is used, but more could be added to build engagement and skills and improve the quality of student work or some of the technology/ equipment used does not enhance the quality of students' skills, engagement, and work. Students use the technology with teacher guidance or directions.	Technology/ equipment is not used or is used inappropriately (distracting, unnecessary, too time-consuming to learn). The teacher is the primary user of technology.	BIE, 2010; GEN 2002-2005; Prensky 2010

[1] In addition to the sources listed, the rubric was refined based on feedback and discussion with two of the workshop facilitators (S. Freemeyer, personal communication, August 4, 2011) (P. Ertmer, personal communication, August 16, 2011) (P. Ertmer, personal communication, December 15, 2011).

[2]The Fouts reference refers to the Teaching Attributes Observation Protocol (TAOP) developed by Gayle Y. Thieman, Ed.D. (Portland State University) for Fouts & Associates

[3] This indicator was removed during the analysis of the data as it was found to not be very informative regarding teachers' efforts at implementation of their PBL units.

[4]This reference describes a modified version of the Reformed Teaching Observation Protocol (Piburn et al., 2000).